NEW TWISTS IN THE STUDY OF GRAVITY WAVE EMISSION IN SYSTEMS WITH MASSIVE BLACK HOLES

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Traditionlly, gravitational wave emission from a coalescing binary system is computed using point mass approximations (See, e.g., Blanchet et al. 1995 and references therein.) without considering any accretion disk. However, it is believed that in many of the galactic nuclei, there are supermassive central black holes, with mass $\sim 10^{8-9} M_\odot$ surrounded by accretion disks. These accretion disks must be necessarily supersonic on and outside the horizon (Chakrabarti, 1996ab) simply because the radial velocity (in the corotating frame) has to be the velocity of light on the horizon while the sound speed must be smaller. However, supersonic flows are typically sub-Keplerian. Thus, smaller black holes and neutron stars (which are on instantaneously Keplerian orbit and lose energy and angular momentum through gravitational radiation) on their way to coalesce with the central black hole must accrete negative angular momentum from the disk. Assuming that the disk becomes highly sub-Keplerian, the ratio of the rate of lose of angular momentum due to such accretion and that due to gravity waves is given by (Chakrabarti, 1996c), $R \sim 1.5 \times 10^{-7} \rho_{10} {T_{10}}^{-3/2} x^4 M_8^2$, where ρ_{10}, T_{10}, x and M_8 are the density in units of 10^{-10} g cm^{-3}, temperature in units of 10^{10}K, binary separation in units of Schwarzschild radius (of the primary) and M_8 is the mass of the primary in units of $10^8 M_\odot$. At around $x = 10$, where, typically, the pressure maximum occurs in a thick accretion disk, and with $M_8 = 10 = \rho_{10} = T_{10} = 1$, we have $R = 0.015$. Thus, for every one hundred orbits, the companion will lose 1.5 orbits due to accretion of negative angular momentum from the disk. Here, the frequency of the gravity wave is about 0.008Hz. These waves, together with the deviation from a standard diskless two-body coalescence template could be easily detectable by the recently proposed gravitational wave detectors, such as LISA and VIRGO.

As an example, in Fig. 1a, we show the ratio $R_l = l_{disk}/l_{Kep}$, of the disk and the Keplerian angular momentum distributions in the case when the flow passes through the inner sonic point at $x = 2.3$. Other parameters are $\gamma = 5/3$, $l_{in} = 1.7$ and the viscosity parameter is: $\alpha = 0.02$. The disk deviates from a Keplerian disk at $r_{tr} = 90$ for these parameters. In Fig. 1b, we show the ratio R as a function of the radial distance when the accretion rate is $1000 \dot{M}_{Eddington}$. The peak correction of the loss rate due to the presence of the disk is about ten percent which linearly goes down with the accretion rate. Fig. 1c shows the number of times the companion orbits the primary with (solid) or without (dashed) the disk component as a function of time origin of which chosen at the instant the disk deviates from a Keplerian disk.

The important point to note is that this result is independent of the mass of the companion as long as it is very small compared to the primary. Second, the phase shift from a standard template (computed without the accretion disk) directly determines the nature of the sub-Keplerian flow. Third, since sub-Keplerian flow also act as a Compton cloud (which may be hot or cold depending on the accretion rate), the fitting of the spectra in UV/soft X-ray regime with standard models (Chakrabarti & Titarchuk, 1995) from the same galaxy would give additional information (such as the accretion rate, the optical depth and the size of the cloud). Together with the phase shift of the gravitational wave data, one could obtain a complete picture of the accreting black hole system at the galactic center.

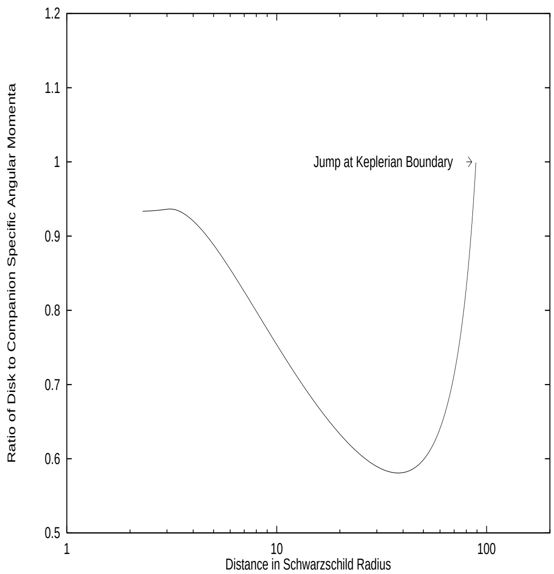

Fig. 1a: Ratio of the disk to Keplerian angular momentum distributions after the flow deviates from a Keplerian disk at $x = 90$.

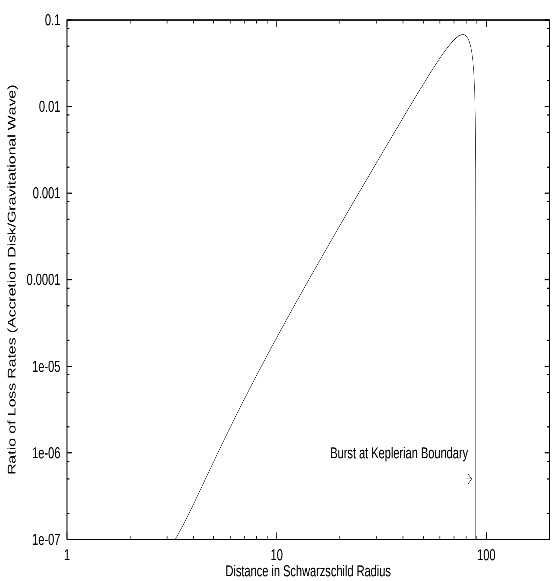

Fig.1b: Ratio of the rate of loss of angular momentum due to negative angular momentum accretion and the rate due to gravitational wave emission when the accretion rate is a thousand times the Eddington rate.

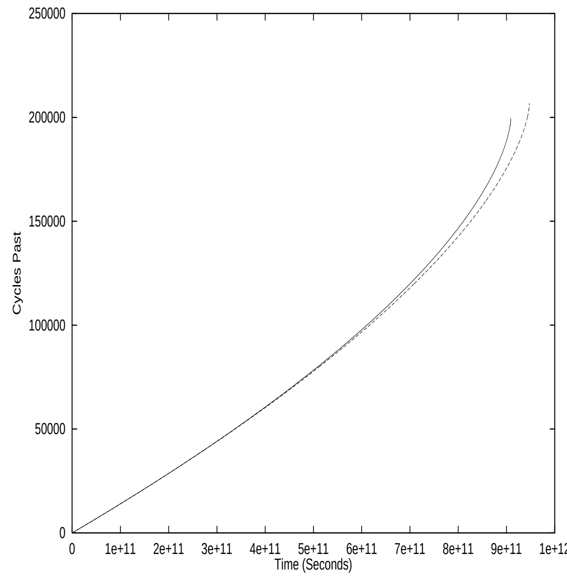

Fig.1c: Number of times companion orbits the primary with (solid) or without (dashed) the disk taken into account.

In some cases the accretion flow becomes *super-Keplerian* before becoming sub-Keplerian near the horizon (Chakrabarti, 1996abc). In these cases the low-mass companion will accrete positive angular momentum from the disk, and in some extreme situation, this compensates for the loss due to gravity waves. As a result, the companion orbit will remain unchanged (Chakrabarti, 1993). Such systems, stability of which has been verified by detailed numerical simulations (Molteni et al. 1994) would be steady sources of gravity waves with constant frequency and amplitude.

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